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Assessment of Physicochemical Water Quality in a Protected Wetland Area: The Case Study of Garaet Hadj-Tahar (Skikda, Northeastern Algeria)

Ines Houhamdi[1], Amel Bouakkazel[2], Bouaguel Leila[3], Karim Loucif[4], Habiba Major[5], Lamine Sayad[6], Mouslim Bara[7*], Moussa Houhamdi[8]

[1]Laboratoire Biologie, Eau et Environnement (LBEE), Faculté SNV-STU, Université 8 Mai 1945 Guelma. BP. 401 24000, Guelma, Algeria
[2]Department of Biology, Faculty of Life and Nature Sciences, Abbes Laghrour University, BP. 1252, Khenchela 40004, Algeria
[3]Department of Biology, Faculty of Sciences and Nature, University Mohamed CherifMessaadia. Souk-Ahras, 41000, Algeria
[4]Laboratory of Environmental Sciences and Agro-Ecology. Faculty of of Natural and Life Sciences. University Chadli Bendjedid- El Tarf – Algeria
[5]Laboratoire Géodynamique et Ressources Naturelles. Faculty of Sciences de la Terre University Badji Mokhtar Annaba, 23000 Algérie
[6]Laboratoire Ressources en eau et développement durable. Faculté des Sciences de la Terre. University Badji Mokhtar Annaba, 23000 Algérie
[7]Laboratoire de Zoologie Appliquée et d'Écophysiologie Animale, Faculté des Sciences de la Nature et de la Vie, Université de Béjaïa, Algérie
[8]Water and Environment Biology Laboratory (LBEE). Faculty of Natural and Life Sciences and Earth and Universe Sciences (New campus). University 8 May 1945, BP: 401, Guelma 24000, Algeria

Corresponding author: mouslim.bara@gmail.com

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ABSTRACT

Garaet Hadj-Tahar wetland is part of the Guerbes-Sanhadja complex in northeastern Algeria, covering an area of 230km². The aim of this study was to assess the physicochemical quality of the surface waters in this Garaet. Sampling was carried out at two different sites over a 12-month period (November 2021 to October 2022). The results of the physicochemical analyses expressed a very low dissolved oxygen (0.56 to 0.94mg/ l). The concentrations of nutrients, particularly nitrites and orthophosphates, were extremely high (0.94 and 7.63mg/ l, respectively), indicating that the water body is highly polluted. High concentrations of chlorides and magnesium, with values of Cl^- = 1023 mg/l, Mg^{2+} = 108 mg/l, are attributed to the leaching of existing geological formations. PCA and HAC analyses confirm the degraded quality of water in Garaet Hadj Tahar due to agricultural pollution. This organic pollution is highly excessive where the OPI reached its maximum (174) during the intensive agriculture activity, in October. The protection of this wetland is a major concern and requires the rational use of chemical fertilizers and the treatment of wastewater discharged into this natural ecosystem.

INTRODUCTION

Recently, the wetlands conservation appears as one of the priorities for managers. This is due to the importance of the heritage they represent and the functions they perform **(Sun *et al.*, 2015)**. The last few decades have been marked by the regression of

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wetlands worldwide. However, their preservation is an absolute necessity because the utility of these areas is now clearly demonstrated **(Sun *et al*., 2015)**. The importance of wetlands is not in their total area, as they only cover 6% of the Earth's land surface **(Mitsch & Gosselin, 1993)**, or about 1.5% of the planet, but in their location in the landscape, their structure and the full range of processes occur there in a unique way **(Sun *et al*., 2015; Gao & Zhou, 2023)**.

Protecting the natural environment preserves the quality of water against urban or industrial pollution **(Loucif *et al*., 2020; Attoui *et al*., 2024)**. There is an urgent need for an integrated and more appropriate approach to watershed and water management for the conservation of wetlands. Measures must be taken immediately to halt the decline of wetlands currently exploited at unsustainable levels. However, wetlands are very fragile and face significant degradation on a global scale. The threats remain severe and are becoming widespread, including deterioration and harm to the environment, depletion of natural resources, and water pollution, which are a major concern **(Sayad, 2015**; **Loucif *et al*., 2024)**.

Wetlands present a vulnerable environment since their essential ecological functions are altered, their economic, cultural, scientific, and recreational value is heavily impacted, and their existence is seriously threatened **(Aissaoui & Bara, 2022; Loucif & Chenchouni, 2024)**.

Algeria hosts a wide range of highly diverse wetlands such as lakes, lagoons, marshes, sebkhas. Algeria's accession to the Ramsar Convention was effective in 1984. To date, 42 sites are listed on the Ramsar list of internationally important wetlands, covering an area of 2,958,704 ha, representing 0.78% of the national territory (compared to 0.02% and 0.08% for Morocco and Tunisia, respectively). However, the demographic growth and the increasing need for water resources have exacerbated the threat to the ecological integrity of wetlands and the well-being of humans and animal and plant species dependent on them **(Bernard, 2016)**.

This survey was conducted in Garaet Hadj-Tahar (Skikda, northeast Algeria) during a biological cycle (November 2021 to October 2022). The study aimed to assess the quality of this wetland using two pollution indices: (1) the Lisec-Index and (2) the Organic Pollution Index. Additionally, monthly physicochemical variations were measured using 13 parameters, categorized into three groups: *in situ* parameters, organic parameters, and cation and anion parameters. Hierarchical clustering was also conducted to group these physicochemical parameters.

MATERIALS AND METHODS

1. Study area

Garaet Hadj-Tahar (36°51’50’’ N, 07°15’57’’ E) is part of the Guerbes-Sanhadja wetland complex, Skikda, Numidie occidentale, north-east Algeria, with a surface area of

500 ha and classified as a Ramsar site since February 2001 **(Metallaoui & Houhamdi, 2008**; **Metallaoui *et al*., 2009**; **Merzoug *et al*., 2014)** (Fig. 1). This freshwater ecosystem plays an important role for waterbirds, with many species using it throughout the year. It is located about twenty kilometers from the Mediterranean and has a very elongated oval shape, exhibiting a very abundant floristic diversity. We found *Nymphaea alba*, *Typha angustifolia*, *Phragmites australis*, *Scirpus maritimus*, *S. lacustris*, and *Iris pseudoacorus*. This Garaet is bordered by a belt of vegetation primarily composed of *Juncus acutus*, *J. maritimus*, *Olea europea*, *Asphodelus aestivus*, *Rubus ulmifolius*, and grasslands of Gramineae, with the most abundant species being *Cynodondactylon* and *Paspalum distichum* **(Merzoug *et al*., 2015**; **Abdi *et al*., 2016**; **Tabouche *et al*., 2016)**.

The wetland complex is one of the most rainfall-rich regions in Northeast Algeria, with an average annual rainfall of 744mm **(Bara *et al*., 2013; Amorabda *et al*., 2015; Bara & Segura, 2019)**. A significant portion of this rainfall contributes to the evapotranspiration process, amounting to 456mm **(Daifallah, 2017)**, a considerable quantity facilitated by the presence of large water bodies. The lands surrounding the site are exclusively used by local residents for the cultivation of cereals, primarily durum wheat (*Triticum durum*). The average depth of the water varies between 0.8 and 1.20 meters, increasing abruptly following heavy rainfall, as the Garaet is essentially a basin that continually receives runoff from the surrounding mountains.

2.2. Sampling method

The chemical composition of water (surface water, shallow groundwater, and gravel aquifers) is often influenced by the dissolution effect of geological formations, industrial discharges, and agricultural activities **(Zenati, 1999)**. This determins its quality, thus affecting its potential use for drinking water supply or other purposes (the irrigation) **(Bourouga, 2015)**.

The two sampling stations were selected on the Garaet to ensure greater representativeness and accessibility **(Boubguira, 2015)**, enabling a comprehensive understanding of the physical and chemical processes that define the functioning of this ecosystem.

The physicochemical parameters (pH, dissolved oxygen, and electrical conductivity) were measured *in situ* using a multi-parameter 340I-/SET WTW (Wissenschaftlich–TechnischeWerkstatten GmbH & Co.KG). Water samples were collected in polyethylene bottles on-site and transported under cold conditions (4°C) to the laboratory **(Rodier, 2009)**. The physicochemical analyses of the water focused on the following parameters: calcium (Ca2+), magnesium (Mg2+), potassium (K+), chlorides (Cl-), sulfates (SO42-), suspended solids (SS), and organic elements: ammonium (NH4+), nitrates (NO3-), nitrites (NO2-), and phosphates (PO43-).

A UV/Vis spectrophotometer was used to measure all these parameters **(Perkampus, 2013; Shi *et al*., 2022)**, except for sulfates (SO_4^{2-}), which were measured by colorimetry, and suspended solids, measured by filtration using fiberglass filters **(Bertolacini & Barney, 1957; Rejsek, 2002)**.

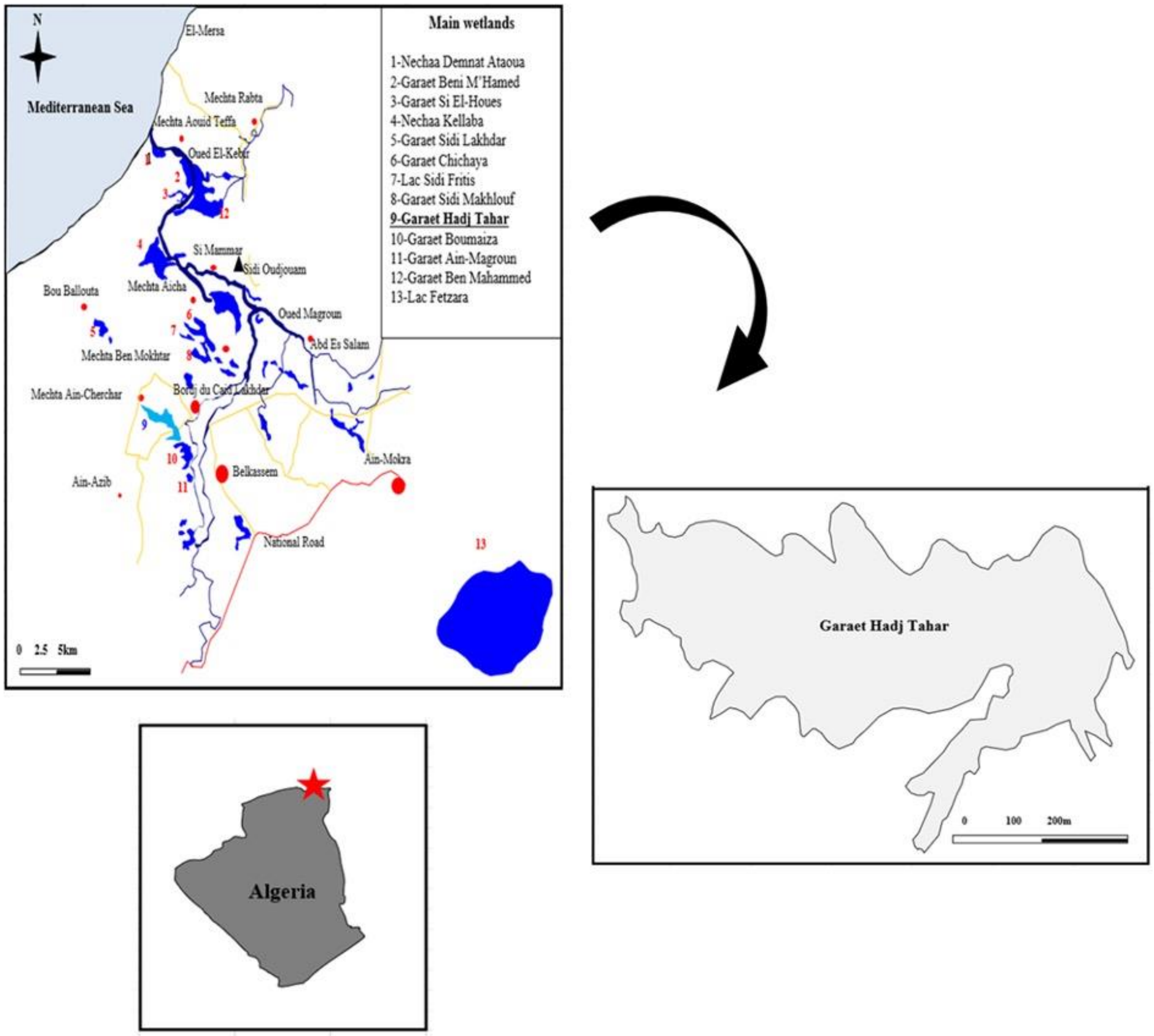


Fig. 1. Geographical situation of the study area (Garaet Hadj-Tahar, Skikda).

2.3. Calculation of pollution indices

Two main pollution indices were calculated using standard formulas: the Lisec-index and the organic pollution index. The Lisec index was determined by summing the classes of dissolved oxygen, ammonium, and orthophosphate and multiplying the result by 1.33 **(Beckers & Steegmans, 1979)**. The organic pollution index was calculated by summing six parameters—dissolved oxygen, nitrate, nitrite, ammonium, orthophosphate, and chlorides—and dividing the total by 6 **(Kherici, 1997)**.

2.4. Statistical analysis

Principal component analysis (PCA) was applied on the hydro chemical analyses of surface waters of Garaet. This was conducted to characterize the water chemistry and the various significant correlations between chemical elements in order to understand the mechanism of this chemistry and to provide a preliminary idea of the pollutants and their sources.

Hierarchical ascending classification (HAC) was used to study the phenomena behind the mineralization of the waters. It also allows for the classification and grouping of variables into distinct classes, which highlight the major poles of mineralization.

To conduct these two analyses, STATISTICA 7 software was used, and the assembled matrix consisted of physicochemical variables in two sampling stations (13 × 2).

RESULTS

1. Variation of physicochemical parameters

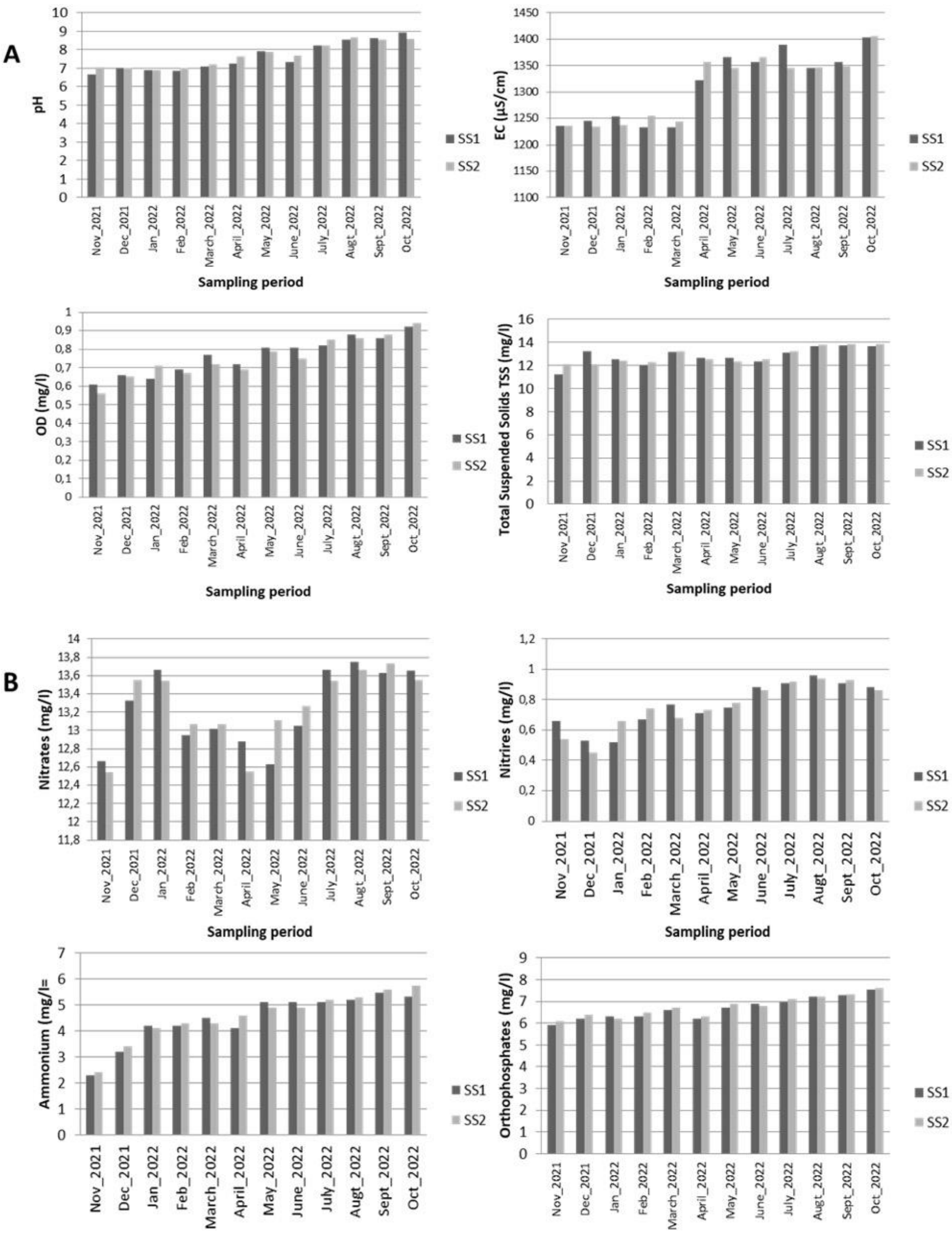
The surface water of Garaet Hadj-Tahar exhibited normal pH values ranging from 6.67 to 8.65 (Fig. 2), indicating a neutral environment. In most natural waters, the pH is typically between 6 and 8.5, whereas in warm waters, it can range from 5 to 9 **(HCEFLCD, 2007)**. The electrical conductivity values range from 1233.56 to 1405.66µS/ cm. Garaet Hadj-Tahar presents an environment with low suspended solids, ranging from 11.22 to 13.85mg/ l, which is below the required standards (Fig. 2).

The presence of Ca2+ and Mg2+ ions in water is mainly linked to two natural origins: either the dissolution of carbonate formations (CaCO3, MgCO3) or the dissolution of gypsum formations (CaSO4). The calcium concentrations in the surface waters of Garaet Hadj-Tahar are below 100mg/ l, with an average of 85mg/ l. The magnesium concentrations vary from 53 to 61mg/ l, indicating moderately soft water. Potassium reached the maximum in in September and October with a value of 108mg/ l, the concentration of this cation graduates significantly between the start and the end of the study (from approximately 80mg/ l to the maximum).

The chloride concentrations in Garaet El Hadj Tahar exceeded 1000mg/ L, while sulfate levels remain significantly lower, rarely surpassing 170mg/ L and fluctuating between 121 and 166mg/ L (Fig. 2). The study recorded an average nitrate concentration of 13.25mg/ L. However, nitrite levels exceed the standard threshold of 0.1mg/ L, ranging from 0.45 to 0.95mg/ L, though they remain lower than those reported by **Drouiche *et al*. (2022)** in neighboring areas, such as the Jijel region.

The values of orthophosphates in the surface waters of Garaet Hadj-Tahar ranged from 5.9 to 7.63mg/ l, indicating highly polluted water according to the ANRH standard of 2001 (Fig. 2).

The Lisec-index showed a significant value of 13.3, corresponding to moderate pollution, while the organic pollution index (OPI) reached 167.55, indicating excessive pollution in Garaet Hadj Tahar. The OPI curve increased exponentially and significantly between November 2021 and October 2022, with the maximum pollution level recorded at the end of October 2022 (OPI = 174) (Fig. 3). The values of the Lisec-index were lower compared to other regions of the country (14.83 in western Algeria) **(Alliouche *et al*., 2022)**. In contrast, **Alliouche *et al*. (2022)** reported that the OPI never exceeded a value of 4 in the eastern and western parts of Algeria.


A
pH
EC (µS/cm)
OD (mg/l)
Total Suspended Solids TSS (mg/l)
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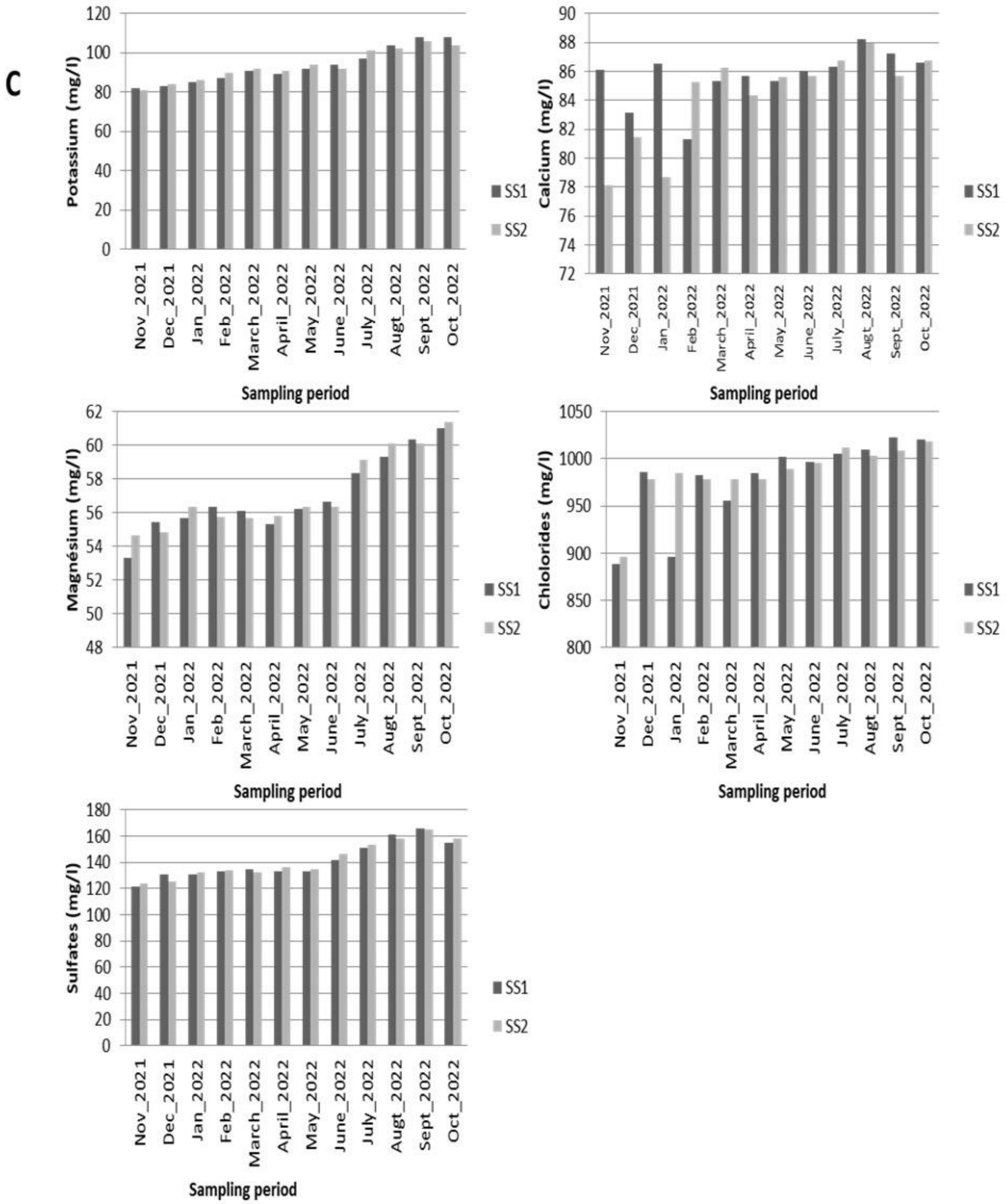

Fig. 2. Annual variation of physicochemical parameters in Garaet Hadj-Tahar (Skikda, northeas Algeria) A: *in situ* parameters, B: organic parameters, C: cation and anion parameters

2. The relationship between physicochemical parameters

The data for the two stations (Table 1) consisted of 13 variables (pH, electrical conductivity, dissolved oxygen, suspended solids, nitrates, nitrites, ammonium, phosphates, calcium, magnesium, chlorides, potassium, and sulfates), represented by Max/Min, mean ± SD per station of the samples collected.

Table 1. Mean, minimum, maximums valus of physicochemical parameters in Garaet Hadj-Tahar (Skikda)

	Sampling station 1				**Sampling station 2**			
	Mean	Min	Max	SD	Mean	Min	Max	SD
pH	7,62	6,67	8,94	0,79	7,70	6,91	8,65	0,67
CE	1311,60	1233,55	1402,33	66,17	1309,94	1234,22	1405,66	63,01
OD	0,77	0,61	0,92	0,10	0,76	0,56	0,94	0,11
MES	12,83	11,22	13,75	0,75	12,86	12,11	13,85	0,69
NO3-	13,24	12,63	13,75	0,42	13,27	12,54	13,73	0,41
NO2-	0,76	0,52	0,96	0,15	0,76	0,45	0,94	0,16
NH4+	4,48	2,30	5,47	0,96	4,56	2,40	5,75	0,96
PO43-	6,68	5,90	7,55	0,51	6,77	6,10	7,63	0,49
Ca2+	85,65	81,33	88,20	1,83	84,37	78,16	87,92	3,20
Mg2+	57,00	53,33	61,02	2,28	57,20	54,66	61,37	2,31
Cl-	979,42	889,00	1023,00	44,52	985,00	896,00	1018,00	31,58
K+	93,33	82,00	108,00	9,19	93,58	81,00	106,00	8,10
SO42-	141,00	121,00	166,00	13,98	141,50	124,00	165,00	13,94

The correlation coefficient between the variable and the considered axis represents the contribution of the variable to the composition of the principal factor axis. The higher the coefficient, the more the variable contributes to the design of this axis.

The strong correlations between potassium and sulfates ($r = 0.97$), potassium and magnesium ($r = 0.96$), and magnesium and sulfates ($r = 0.96$) are attributed to base exchanges among these elements (Table 2). Electrical conductivity shows a positive correlation with chlorides, sulfates, magnesium, and potassium ($r = 0.42$, $r = 0.71$, r =

0.72, and r = 0.78), reflecting the mineralization of the waters. This mineralization is influenced by the lithological characteristics of the terrains—dominated by chlorides, sulfates, potassium, and magnesium—traversed by these waters, as well as geological interactions with surface waters in the study area.

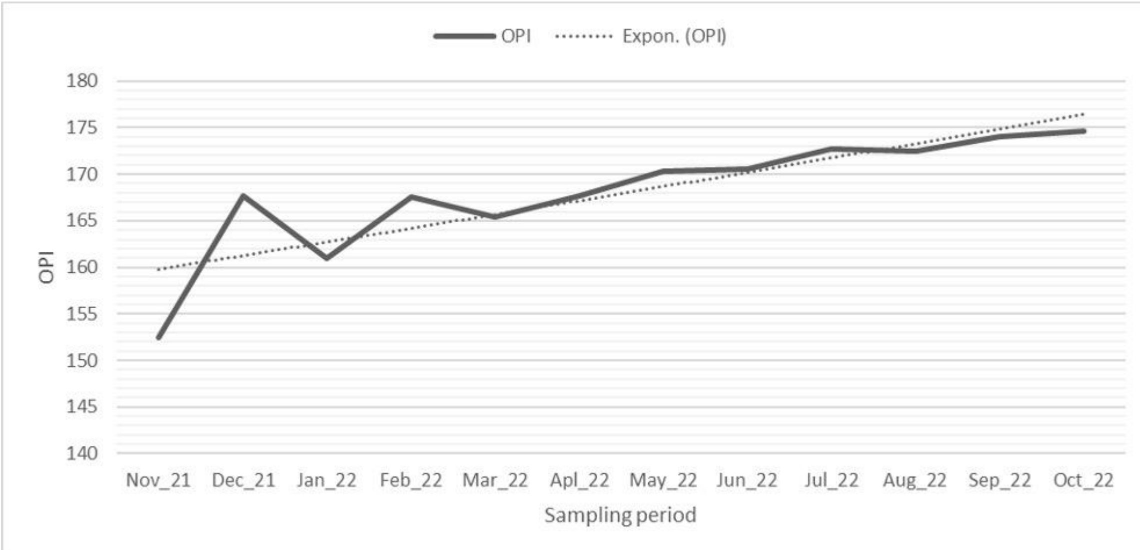

Fig. 3. the trend of OPI variation during the sampling period in Garaet Hadj-Tahar (Skikda, Algeria)

Dissolved oxygen is very significantly correlated with nutrients such as nitrites (r = ammonium = 0.89%), and phosphates (r = 0.96%), indicating an anaerobic and polluted environment. The correlation matrix for the second station (Table 2) shows the same findings as the first station and revealed very significant correlation relationships, particularly among the elements related to mineralization.

The examination of the coefficients of other variable pairs could also provide additional information about the state of the surface waters of Garaet Hadj-Tahar. The mineralization of the waters is linked to the alteration of existing geological formations by water.

Analysis of the PCA circles (F1 x F2)

For the first station, the correlation circle formed by axes F1 and F2 (Fig. 4) provides 84.41% of the total information. Axis F1 represented75.85% of this information. The distribution of variables on the F1 axis plane showed a grouping of the majority of these variables related to mineralization. These included phosphates, calcium, and sulfates. This group was positively correlated with the F1 axis. Along the F2 axis, calcium and nitrates were grouped, with the latter representing the information related to nitrogen pollution in surface waters due to anthropogenic activities. The total information from the F1 x F2 correlation circle for the second station represented 88.20% (Fig. 4), with axis F1 alone accounting for 80.64% of this information. The same observations recorded at the first station can be drawn, except that axis F2 was represented solely by nitrates, which are caused by livestock activity.

Table 2. Correlation matrix of all physicochemical parameters in Garaet Hadj-Tahar (Skikda)

	pH	CE	OD	MES	NO^{3}_{-}	NO^{2}_{-}	NH^{4+}	PO^{4}_{3-}	Ca_{2+}	Mg_{2+}	Cl_{-}	K+	SO^{4}_{2-}
pH	1,00												
CE	0,86	1,00											
OD	0,92	0,84	1,00										
MES	0,78	0,52	0,73	1,00									
NO3-	0,60	0,36	0,45	0,73	1,00								
NO2-	0,80	0,77	0,89	0,50	0,34	1,00							
NH4+	0,78	0,77	0,89	0,68	0,48	0,75	1,00						
PO43-	0,93	0,80	0,96	0,76	0,62	0,84	0,88	1,00					
Ca2+	0,58	0,56	0,51	0,39	0,47	0,57	0,41	0,54	1,00				
Mg2+	0,93	0,72	0,89	0,81	0,73	0,75	0,82	0,96	0,45	1,00			
Cl-	0,76	0,73	0,82	0,69	0,31	0,69	0,75	0,74	0,07	0,75	1,00		
K+	0,95	0,78	0,94	0,75	0,60	0,86	0,83	0,97	0,59	0,96	0,74	1,00	
SO^{4}_{2-}	0,90	0,71	0,87	0,80	0,74	0,82	0,80	0,92	0,56	0,95	0,73	0,95	1,00

The hierarchical ascendant classification or dendrograms for the two stations (Fig. 5) confirm the results of the PCA and reveal the existence of two main groups. The first group was represented by chlorides and electrical conductivity, which form the mineralization pole, while the second is formed by the rest of elements.

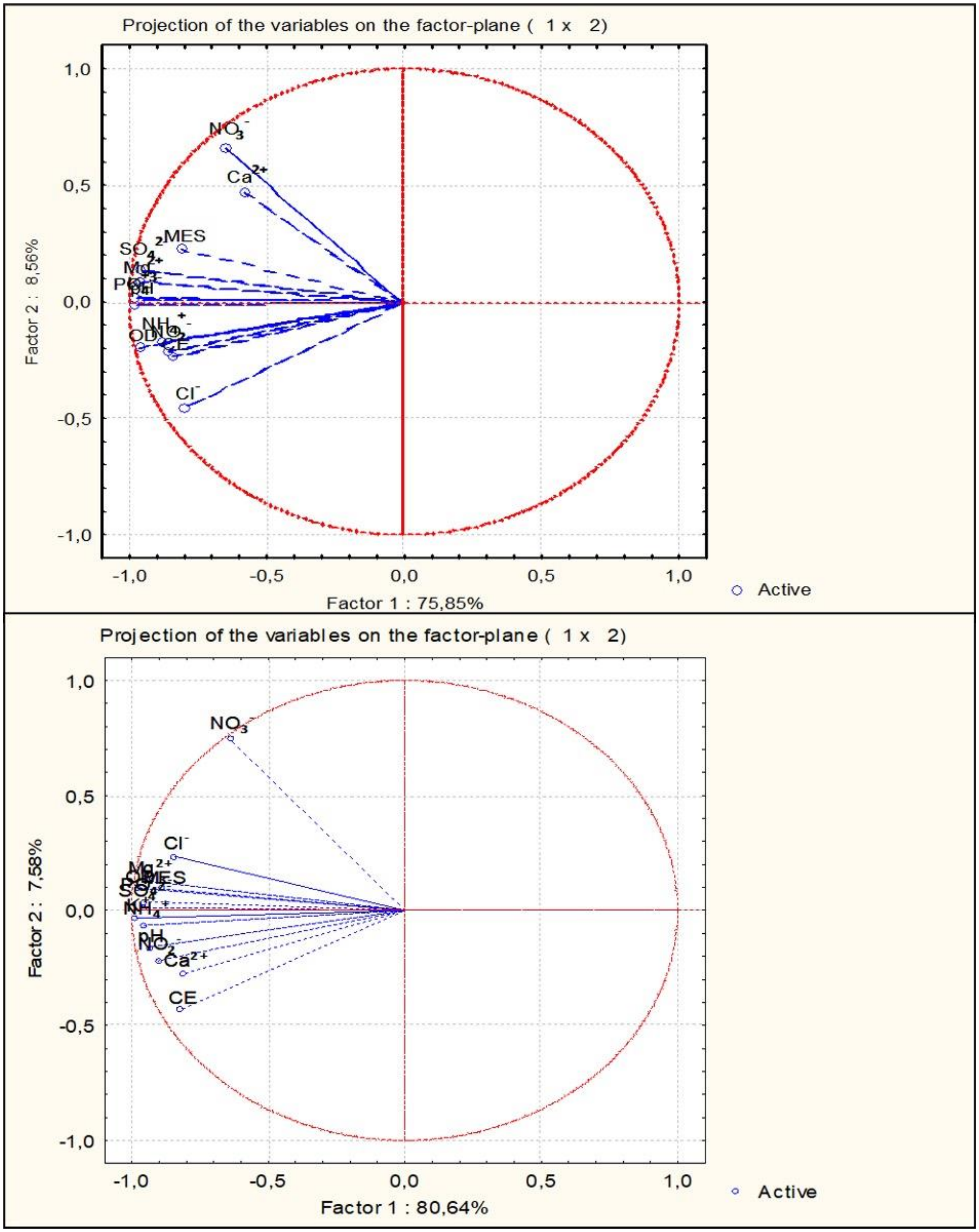

Fig. 4. PCA map showing the correlation between physicochemical parameters in Garaet Hadj-Tahar (Skikda, northeast Algeria)

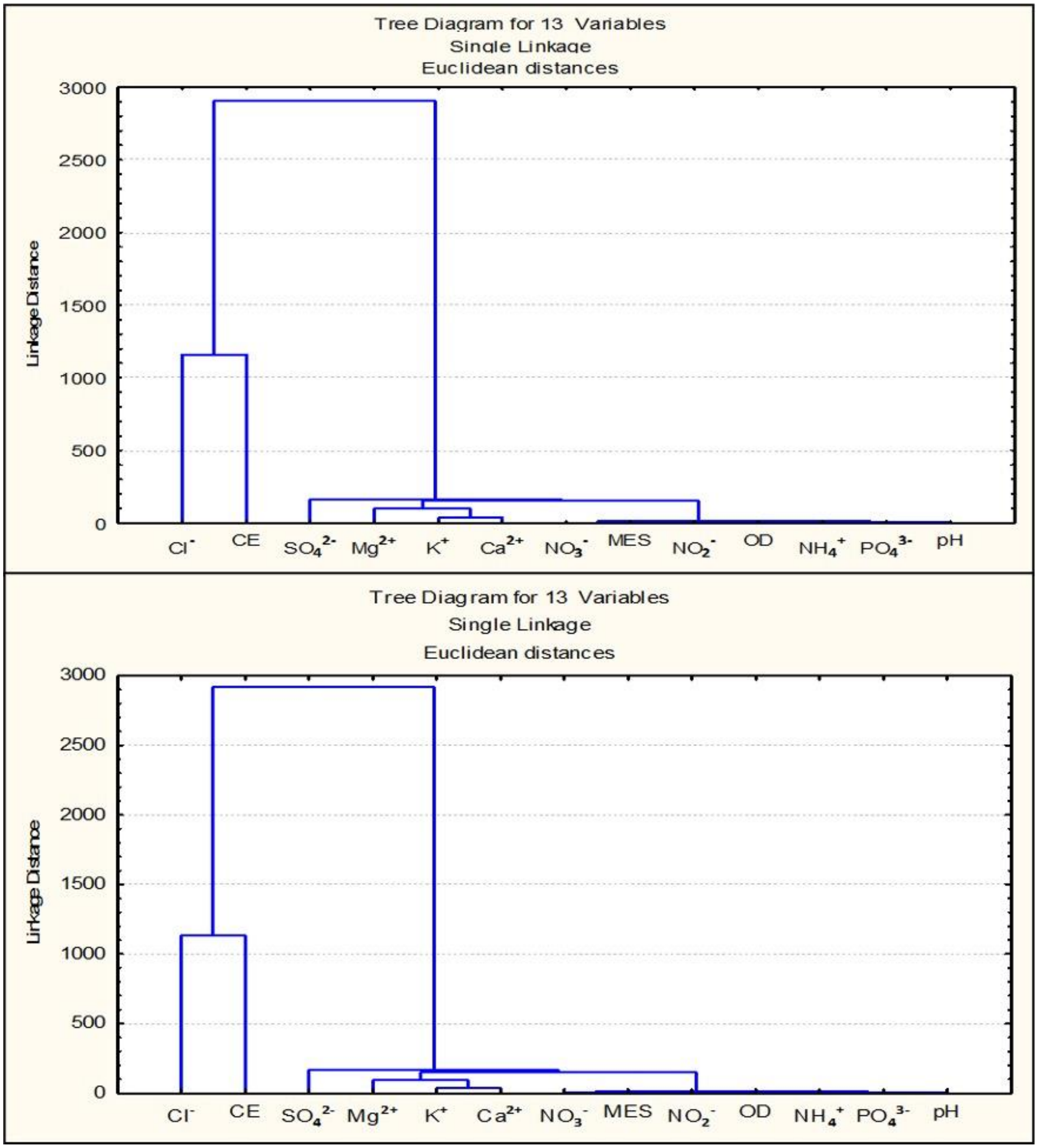

Fig. 5. HAC analysis grouping physicochemical parameters in Garaet Hadj-Tahar (Skikda, northeast Algeria)

DISCUSSION

In this study, we evaluated the level of organic pollution in Garaet Hadj-Tahar using 13 physicochemical parameters. Our findings indicated that the wetland experienced moderate to excessive pollution. The sources of pollution were diverse, primarily including intensive agricultural activities and discharged wastewater. A high level of pollution was detected in this protected wetland despite its conservation status. Organic pollution can reach critical levels during periods of intense agricultural activity.

Oxygen is an excellent indicator of the functioning of the Garaet, indicating an environment that is very poor in dissolved oxygen and reflecting poor water quality. A low dissolved oxygen content leads to an increase in the solubility of toxic elements that are released from the sediments. According to our results and based on the rating grid in Monod, 1989, the waters of Garaet Hadj-Tahar are of a fair quality.

The main sources of magnesium are ferromagnesian minerals from igneous rocks, magnesium carbonates from sedimentary rocks, and the dissolution of chemical fertilizers rich in NPK used in agriculture **(Osman, 2013)**. Chlorides can have several sources and are mainly related to the dissolution of salt-rich soils. They can also originate from human activities, such as road salting or contamination from wastewater **(Beaudry & Henry, 1984; Loucif *et al*., 2020)**. Sulfates originate from the solubility of calcium sulfate in gypsum rocks and from the oxidation of sulfides present in the rocks.

The nitrate content in water is generally higher than that of nitrites **(van den Brand *et al*., 2020)**. A high concentration of nitrites indicates an organic pollution and a toxic environment (see pollution indices). Despite the OPI index, which is considered more realistic and provides a more accurate assessment during monitoring than the Lisec index **(Alliouche *et al*., 2022)**, our findings show moderate to excessive organic pollution in the Garaet.

The presence of ammonium in significant quantities is an indicator of contamination from human or industrial discharges. Generally, well-oxygenated water contains only trace amounts of ammonium. Despite decades of efforts to reduce pollutant discharges into the environment, the excessive enrichment of aquatic environments with nutrients remains a major issue **(Chambers, 2001)**. Ammonium is due to the reduction of nitrates and nitrites from chemical fertilizers and pesticides used in agriculture. This increase in concentrations also suggests pollutant inputs from discharges of urban areas in the study zone **(Hedjal *et al*., 2018)**.

The enrichment in orthophosphates can be explained by the effect of wastewater discharges **(Neal *et al*., 2000)** and the excessive use of chemical fertilizers. Phosphates are considered the main contributor to the eutrophication of surface waters, along with nitrogen.

Our findings conclude that Garaet Hadj Tahar contains two water groups: chlorides (water weakly mineralized), and the remaining elements (water highly mineralized). In contrast, numerous studies conducted in the surrounding areas have identified three distinct water types—highly, moderately, and weakly mineralized water **(Zahi *et al*., 2024)**.

CONCLUSION

The physicochemical study of Garaet Hadj-Tahar over a one-year period reveals a degraded environment with low dissolved oxygen levels. The high concentrations of potassium, nitrites, and phosphates indicate organic pollution of anthropogenic origin due to the excessive use of chemical fertilizers in agriculture. The high concentrations of chlorides are due to the leaching of the region's geological formations. Principal component analysis (PCA) and hierarchical ascendant classification (HAC) have supported and confirmed the polluted state of these waters.

Protecting Garaet Hadj-Tahar requires a combination of pollution control, sustainable land use, and conservation efforts. Here are some key recommendations: (1) Promoting sustainable farming, (2) Regulating fertilizer use, (3) Promoting eco-friendly sanitation, (4) Regular water quality monitoring, (5) Reforestation and soil conservation and (6) Encouraging environmental education programs.

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